Mapping Environmental Contaminants at Ray Mine, AZ

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Introduction:

Airborne Visible and InfraRed Imaging Spectrometer (AVIRIS) (Green et al., 1998) data was collected over Ray Mine as part of a demonstration project for the Environmental Protection Agency (EPA) through the Advanced Measurement Initiative (AMI) (EPA, 1997). The overall goal of AMI is to accelerate adoption and application of advanced measurement technologies for cost effective environmental monitoring by regulators, regulatee's and their contractors. EPA is also interested in developing protocols that use commercial software to enable commercial partners to perform such work at other high priority EPA sites. The Ray Mine site was selected to demonstrate the benefit of advanced remote sensing technologies for the detection of environmental contaminants due to mineral extraction at an active open pit mine (Mace Personal Communication, 1998). Jet Propulsion Laboratory's role in this pilot study is to provide data and perform calibration, data analysis, and validation of remote sensing data including AVIRIS.

Reflectance retrieval was performed on calibrated AVIRIS radiance data using outputs generated by the MODTRAN (Berk et al., 1998) radiative transfer model and field spectra collected for the purpose of calibration. We reported early results in McCubbin et al. (1998) that were based on the Spectral Angle Mapper algorithm in the ENVI commercial software package. Here we present more advanced applications of the ENVI software using n-Dimensional Partial Unmixing to identify image-derived endmembers that best match target materials reference spectra in the spectral libraries provided in ENVI. After identification of image endmembers, we then used the Mixture Tuned Match Filter algorithm (Boardman, 1998) to map the endmembers within the AVIRIS scenes. This procedure produced maps of four different minerals that are associated with mine generated acid waste.

Background:

Ray Mine is located approximately 100 km E-SE of Phoenix, AZ, and is between the Tortilla and Dripping Springs Mountain Ranges. It is situated within the Mineral Creek watershed, a tributary of the Gila River. Ray Mine has been active for over a century, with milling operations present most of that time. AVIRIS data was acquired over Ray Mine on four separate dates from April 16, 1997, to October 3, 1998. The specific objective is to map sources of Acid Mine Drainage (AMD) within the area of active mining. AMD has a source in iron sulfide from natural rock exposures and the mine pit and associated tailings. Weathering of iron sulfide liberates hydrogen ions; which can increase the acidity of surface and ground water. Using Imaging Spectroscopy to map pixels with the diagnostic 2.27 μm feature of the sulfate mineral jarosite may locate sites where sulfide oxidation is occurring, and thus identify potential sources of AMD.

Methods:

We used MODTRAN, a Radiative Transfer Model, to generate look up tables of aerosols and water vapor concentrations that are then processed to generate an equation that finds spectral shifts in the data. A least squares regression is then performed to fit the 0.94 μm water vapor absorption feature. Using the water vapor retrievals, the radiance data was inverted to apparent surface reflectance. Green (1998, et al. 1996) developed this reflectance retrieval method.

After conversion from radiance to apparent surface reflectance all subsequent analyses were performed using the Environment for Visualizing Images (ENVI) software package. A Normalized Difference Vegetation Index (NDVI) image was created and used as a mask to exclude areas of the image with significant vegetation cover; A threshold of 0.2 NDVI was chosen as a maximum value for the mask because that value indicates minimal to no vegetation.

A site-specific reference spectral library was created from several spectral libraries that are in the ENVI software package. The libraries used included those of JPL, USGS Spectroscopy Lab, John Hopkins University, as well as our own Field and Laboratory Spectra. These spectra were convolved to the same spectral resolution as the AVIRIS data sets. For subsequent analyses, spectra were separated into two spectral regions, the first short of 1.2 μm, and the second long of 2.0 μm. This was done to reduce the dimensionality of the data during analysis, as well as to reducing computation time and data volume.

Next data analysis/exploration was performed using the n-dimensional partial unmixing approach (ENVI Tutorials, 1997) to identify image endmembers that represented minerals, including jarosite, that are associated with AMD. The Minimum Noise Fraction (MNF) transformation was performed on the data to further reduce the dimensionality. Using the MNF data, a Pixel Purity Index (PPI) calculation was performed to identify the spectrally pure image endmembers. The PPI image revealed the extreme pixels of the data cloud. The n-D visualizer tool was then used to rotate the MNF data cloud to help find endmembers of interest. Particular classes were initially identified based on absorption features of interest such as the 0.9 μm Fe^{2+} and the 2.2 μm OH^- features. Each class represented anywhere from 2- 15 pixels, from which the mean reflectance spectra were calculated. These mean spectra were then input into the knowledge based spectral analysts tool to match the image endmembers to reference endmembers. From these results the spectra of each pixel in classes of interest were run through the knowledge based Spectral Analyst to identify which endmembers would be used in the Mixture Tuned Matched Filter (MTMF) algorithm. In order to perform the MTMF it was necessary to use the MNF spectra for each image endmember as input. The resulting output from the MTMF was for each endmember a matched filter image along with the infeasibility image, which represents a measurement in standard deviations away from the endmember spectra. The outputs for each endmember were then ratioed to generate endmember images, showing the spatial distribution of each endmember.

<u>Results:</u>

Figure 1A

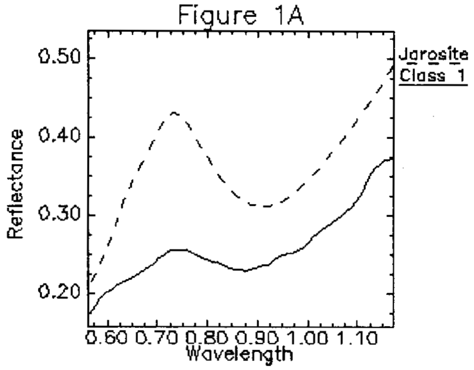


Figure 1B

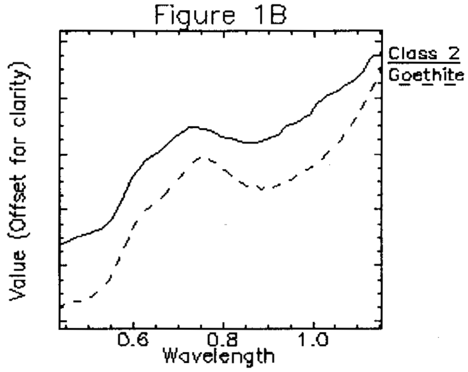


Figure 1C

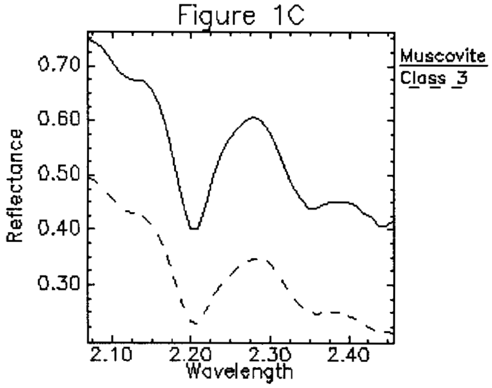
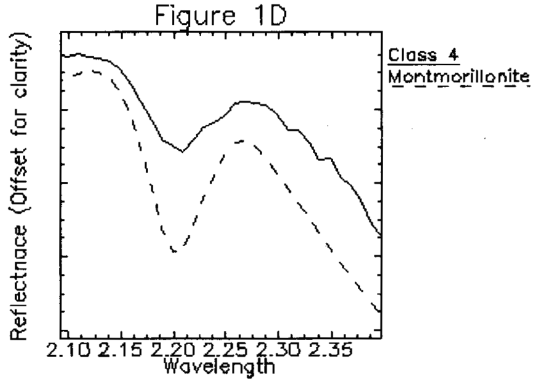
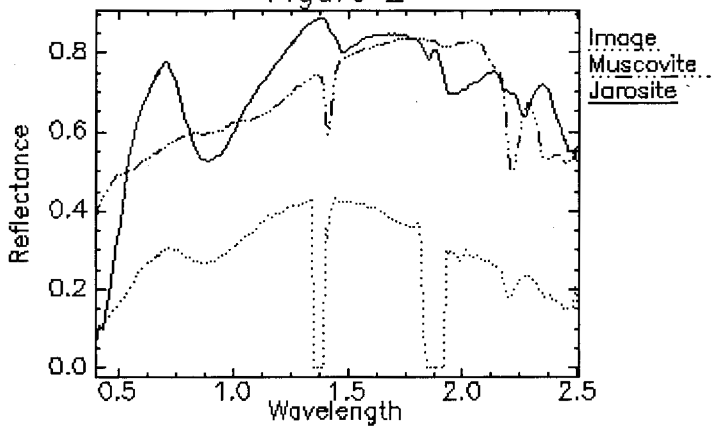


Figure 1D



This procedure produced a map of minerals based on the occurrence of the 0.9 µm Fe^{2+} and 2.2 µm OH^- absorption bands in each pixel forming the AVIRIS image. Figure 1A-D compares image endmember spectra and matched library reference spectra. The same method was applied to map jarosite and goethite using only the position of the 0.9 µm iron absorption band. However due to the importance of jarosite which has a diagnostic 2.27 µm absorption band, we used the entire AVIRIS spectrum to validate the iron band results. This was done using the longer wavelength region to identify the diagnostic jarosite band at 2.27 µm. The band was not present in the pixels that were identified as jarosite based on the 0.9 µm iron absorption band data alone. Figure 2 compares the image derived jarosite endmember to the reference jarosite spectrum across the full AVIRIS spectrum.

Figure 2



Conclusion:

The absence of the diagnostic 2.27 µm jarosite band in pixels mapped as jarosite suggests that subdividing the AVIRIS spectrum yields results based only on a single iron absorption band which alone may not be diagnostic of jarosite. Lack of the characteristic 2.27 µm absorption band in pixels mapped as jarosite may be caused by mixing of different mineral spectra within the field of view. Muscovite has a feature that could mask the jarosite absorption band located at 2.27 µm (figure 2).

In order to check the validity of these results a stratified sampling method will be employed for each of the mapped classes. Due to active mining operations all pixels are not accessible in the field, so sampling will be biased towards pixels that are accessible. Only after this validation in completed can we state that the method that we used is a proven and effective tool for mapping minerals on environmental concern at Ray Mine or elsewhere.

Acknowledgments:

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